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PROJECT RESULTS

EARTHEN MANURE STORAGE COVERS: THEIR ROLE IN NUTRIENT CONSERVATION AND MANURE STABILIZATION

back

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Background and Objectives

Lagoons have traditionally been the most common storage and treatment system for swine slurry (Overcash et al., 1983). A lagoon is often referred to as an earthen manure storage (EMS) when its treatment effect is not emphasized as is the case in Canada. Open EMSs or lagoons are often the source of offensive odours. The presence of such odours has emerged as a primary public relations issue facing hog producers. Swine manure odours arise primarily from the incomplete decomposition of organic matter by anaerobic degradation. Over 75 malodorous compounds have been identified in swine manure (Barth et al., 1984). Among them, volatile fatty acids, that are intermediate products in the metabolic chain of anaerobic digestion, are the most important group and are usually reported as the major indicators of the offensiveness of odours from manure slurry (Burton, 1997). Installation of covers on manure EMSs is an effective mean for reducing odour emission.

While covers can significantly reduce the amount of odour emissions from an EMS, they also potentially reduce odour sources by providing suitable conditions for anaerobic organisms to stabilise (mineralise) organic matter in manure. Such suitable conditions for anaerobes include preventing natural aeration on the EMS surface and maintenance of higher EMS temperatures. Methane is usually produced in a covered EMS as a by-product of anaerobic digestion under favourable conditions.

From 1998 to 1999, DGH Engineering Ltd. conducted a study to demonstrate the feasibility of a negative air pressure cover system under field conditions. The project proved very successful. The covers and the negative air pressure system functioned effectively during varied climatic conditions year round, including the presence of snow and ice and during periods of high winds. The project was successful in proving the basic underlying concept, that negative air pressure was a feasible means of anchorage for covers under field conditions. The project also positively demonstrated the general physical performance of the cover especially in response to wind forces and in relation to the reduction of odours (DGH,1999). However, issues remain for further study, including:

- Whether an EMS with a negative air pressure cover system has any effect on the conservation of nutrients in the manure. The prevailing current view is that there is noticeable nitrogen loss from an open EMS primarily due to volatilization of ammonia from the storage surface.
- What is the impact of a negative air pressure cover system on the stabilisation of organic matter in manure in an EMS.
- Does an EMS with a negative air pressure cover system have the potential for useful biogas production in a climate similar to that in Manitoba. Although covers in use on lagoons in the southern United States of America have been used to harvest biogas, it is not clear whether similar potential exists for covered EMS in western Canada.

This present study was designed to consider these issues.

Anaerobic Digestion

Anaerobic digestion is a biological process that consists of a series of reactions which are carried out by a mixed group of bacteria in the absence of molecular oxygen. Almost all naturally occurring organic matter and many synthetic organic compounds can be fermented, or digested anaerobically. If partial digestion occurs, intermediate compounds may be produced, including many that are odorous. If the process is carried to completion, gaseous products including methane and carbon dioxide are produced with minimal odorous by-products. Through anaerobic digestion, organic matter is converted in a stepwise fashion to stable end products. Usually, anaerobic biological conversion of organic matter is thought to occur in three steps (Figure 2-1): hydrolysis, acidogenesis, and methanogenesis with each step involving its own unique consortium of bacteria (Metcalf & Eddy, 1991).

The first step involves the enzyme-mediated transformation (hydrolysis or liquefaction) of the higher-molecular-mass compounds into simple, lower molecular weight fermentation end products such as lactate, ethanol, acetate, formate, H_2, propionate, and butyrate. The second step (acidogenesis) involves the bacterial conversion of the compounds resulting from the first step into acetate, H_2, and formate. The third step (methanogenesis) involves the bacterial conversion of the intermediate organic compounds into simpler end products that are about 65% methane and 35% carbon dioxide, with traces of hydrogen sulphide and ammonia (Metcalf & Eddy, 1991, and Schmit & Dague, 1993). Of the three steps, the last one is critical because of the slow growth rate of methane bacteria (2 to 22 days per generation) and its sensitivity to environmental change.

The reactions that occur in the methanogenesis phase can be illustrated as follows:

CH_3COOH ¾ ¾ ¾ ¾ ¾ ¾ ¾ ¾ ® $CH_4 + CO_2$ (2-1)

$4CH_3COOH$ ¾ ¾ ¾ ¾ ¾ ¾ ¾ ¾ ® $3CH_4 + CO_2 + H_2O$ (2-2)

$4H_2 + CO_2$ ¾ ¾ ¾ ¾ ¾ ¾ ¾ ¾ ® $CH_4 + 2H_2O$ (2-3)

$4HCOOH$ ¾ ¾ ¾ ¾ ¾ ¾ ¾ ¾ ® $CH_4 + 3CO_2 + 2H_2O$ (2-4)

$4\,(CH_3)_3N + H_2O$ ¾ ¾ ¾ ¾ ¾ ® $9CH_4 + 3CO_2 + 6H_2O + 4NH_3$ (2-5)

Organic waste stabilisation in anaerobic digestion is accomplished when methane and carbon dioxide are produced. Methane gas is highly insoluble, and its departure from solution represents actual waste stabilisation (Metcalf & Eddy, 1991).

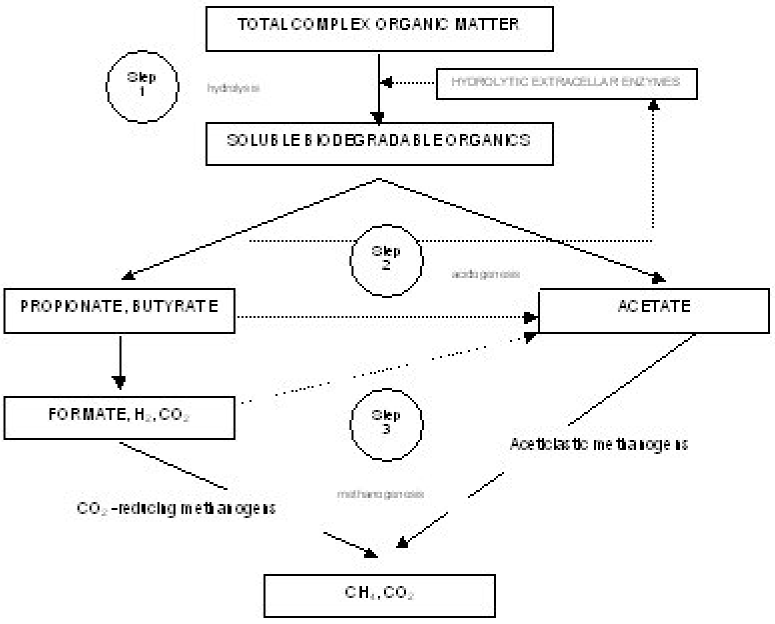

Figure 2-1 Anerobic digestion of organic matter and methane prodution (After Hill et al, 1987)

Anaerobic Digestion of Swine Manure

In the past three decades, anaerobic digestion of swine manure has been intensively investigated, initially focusing on energy recovery and more recently shifting the focus to environmental concerns, including that of odour nuisance. The need for such study is rooted in the belief that anaerobic methods of treatment of manure are more economical than aerobic methods because of the high concentrations of organic components in manure. Loehr (1974) reported that when concentrations of organic components exceeded 4000 mg/L in terms of Chemical Oxygen Demand (COD), anaerobic methods became more economical than aerobic methods. COD of swine manure slurry typically varies between 8,000 and 40,000 mg/L.

There are three potential benefits to the utilisation of anaerobic digestion for animal waste management (Morris et al., 1975):

1. Pollution Control
   - Reduction and stabilisation of organic solids to a more acceptable form.
   - Liquid end-products are less offensive in odour and are more homogeneous to facilitate subsequent handling.
   - Destruction of many pathogenic organisms and weed seeds.
   - Rodents and flies are less attracted to the digested waste.
2. Energy Recovery
   - Production of a combustible gas ¾ methane.
3. Nutrient Conservation
   - Conservation of the fertiliser value originally present in the manure.

Many kinds of anaerobic digesters have been developed for swine manure treatment and as a result the efficiency of the stabilisation of organic components, nutrients conservation and energy recovery have been the subject of much study. Additionally, major factors influencing the performance of anaerobic digesters has also been studied.

It has been found that batch fed digesters are more effective than continuous operations in terms of COD removal. With a hydraulic retention time (HRT) of 10 days, a batch operation digester removed 43% COD, while with a HRT of 16 days, a continuous operation digester removed 23% COD (Cavallero & Genon, 1984). These findings, combined with the concept of aerobic sequencing batch reactors, have resulted in the introduction of anaerobic sequencing batch operations in the treatment of swine manure (Dague & Pidaparti, 1992; Schmit & Dague, 1993).

Temperature is found to be one of the most important factors affecting the performance of anaerobic digestion. It has been found that the optimum temperature ranges for anaerobic digestion are mesophilic (30-38^{o}C), and thermophilic, (49-57^{o}C) (Metcalf & Eddy, 1991).

Lagoon and EMS as Anaerobic Digester

Lagoons are usually classified as aerobic, anaerobic or aerobic-anaerobic according to their organic decomposition mechanisms (Metcalf & Eddy, 1991). Lagoon employed by hog farms are usually anaerobic because anaerobic conditions are dominant, although photosynthesis and surface re-aeration do provide oxygen in the uppermost layers of the stored manure.

Manure treated in a lagoon or stored in an EMS, followed by land application, is the most common method of hog manure management in both Canada and USA (Oleszkiewicz, 2000).

In the United States, earthen basins are referred as to lagoons, which are usually single cell and designed on the basis of organic matter loading (ASAE 2000; and Bicudo et al. 1999). The efficiency of treatment of manure is the primary parameter for lagoon design. Lagoon liquids are recycled for flushing, land applied or discharged into water body. Biomass, mainly anaerobic bacteria, are situated at the bottom of a lagoon for several years to perform the decomposition of organic matter in manure.

In Canada, earthen basins are referred as to earthen manure storages (EMSs) and not lagoons because there is no specific design for treatment requirement of them. The main consideration for an EMS is the holding volume. Minimum required storage volume is usually six months in jurisdictions that restrict winter spreading. (MB, 1998; Oleszkiewicz, 2000). Most EMSs are sized to provide 1 year of storage capacity. EMSs are emptied semi-annually or annually for agricultural land application. Usually, there is little biomass in an EMS at the beginning of its operation, much less biomass in an EMS than that in a lagoon.

Regardless of the intention for treatment or storage, in all cases the earthen basin acts as an anaerobic reactor changing the quality and character of the manure. It has been found that a lagoon or an EMS as an anaerobic reactor possesses the following characteristics:

1. Low organic loading rates;
   Organic lodaing rates agoons are usually very low, ranging from 0.048 to 0.096 kg volatile solids/m^3 of treatment volume per day (ASAE, 2000), compared with anaerobic digesters which range from 2.7 to 17 kg volatile solids/m^3 digester volume per day (Hill, 1984)
2. Fluctuation of operation temperature;
   Unlike traditional anaerobic digesters that are always operated at either constant mesophilic or thermophilic temperatures, lagoon or EMS temperatures fluctuate depending on liquid depth and ambient temperature (Safley & Westerman, 1992).
3. Large open surface area;
   An uncovered (open) lagoon or EMS usually has a large open surface area that inhibits anaerobic reaction in the uppermost layers since even minute amounts of molecular oxygen may be toxic to methanogenic bacteria. Furthermore, some volatile organic matters, such as volatile fatty acids (VFA) that are intermediate products of anaerobic digestion, emit to atmosphere from the surface of the lagoon or EMS resulting in odour problems.

Covered Lagoon and Biogas Recovery
The main purpose for the installation of covers on lagoon or EMS in the past has been for the prevention of odour emissions. As stated earlier, however, other uses for covers on lagoon or EMS include improvements in the anaerobic treatment process and the potential for biogas collection.

Early literature on covers for lagoon was prepared by Melvin and Crammond (1981). They discussed the use of 45-mil (1.14 mm) reinforced Hypalon black fabric on a lagoon in 1979 in Radcliffe, IA. Originally, collected gas was planned to generate power for the farm. The cover was reportedly successful in controlling odours, however, little gas was collected. The researchers believed that low temperatures was one of reasons responsible for the failure to produce much gas.

Safley & Westerman (1989) reported on floating covers placed on anaerobic lagoon to study biogas production. They reported that biogas can be recovered from the surface of anaerobic lagoon using floating covers. They found that biogas production was controlled by volatile solids (VS) loading and lagoon liquid temperature. Biogas production rates were reduced at lagoon temperatures below 13-15^{o}C.

In the spring of 2000, the United States Environmental Protection Agency (USEPA, 2000) reported on several of covered lagoon in the United States, which included 9 swine lagoons and 2 dairy lagoons. Biogas was successfully collected from all of the studied lagoons and biogas collected from 5 swine lagoons were used for generating electricity. The hog operations using lagoon covers were reported to greatly benefit from their manure treatment systems. Digested manure from the covered lagoons was nearly odour free, reduced greenhouse gas emissions, and reduced water pollution potential of swine manure. The electricity generated by biogas production offset 80-90% of the a hog producer’s monthly energy bills. In the case of a 1,000 sow farrow-to-finish facility, the methane recovery investment reduced annual operation and maintenance costs by approximately $36,000 while providing a 34 percent annual rate of return. The USEPA recognises covered lagoon with methane recovery as a win-win manure solution for hog producers and the environment. (USEPA, 1995).

Williams and Woodburg (USEPA, 1995) indicated that covered lagoon with methane recovery systems can only work efficiently in temperate to warm climates.

No literatures on biogas recovery from EMS was found in our literature review.

The Feasibility of Anaerobic Digestion at Low Temperature
Temperature greatly influences the completion of anaerobic digestion since methanogenic bacteria are very sensitive to

changes in temperature (Henry & Heinke, 1989).

The climate in Manitoba is extreme with temperature ranging as high as 40^{O}C in the summer and as low as minus 40^{O}C in the winter. High temperatures in Manitoba seem not to be a problem to anaerobic digestion, but low temperatures may hinder the activity of some anaerobic bacteria responsible for the degradation of organic matter. As a result, the behaviour of methanogenic bacteria at low temperature is critical to organic matter stabilization in EMS in Manitoba.

McCarty (1966) reported that at 5^{O}C the rate of methane fermentation is ten times slower than at 35^{O}C which is the optimum temperature in the mesophilic range. At temperatures of 25^{O}C the rate of methane fermentation is only 1.3 times slower.

van Velsen and Lettinga (1979) believed that anaerobic digestion was ineffective at temperatures below 20^{O}C (psychrophilic) since the conversion of solid material was, as a rule, slow and incomplete at such temperatures.

Gupta & Prakash (1982) considered the operating temperature to be a major component in developing efficient biogas fermentors. They suggested that there was a need for the 'isolation of a microbial strain (of methanogen) that will remain active under low temperature'.

Zeikus & Winfrey (1976) and Baker-Blocker et al. (1977) observed biogas production in anaerobic digestion at 4^{O}C and 5^{O}C, respectively. Ke-Xin & Nian-Guo (1980) described the dramatic change in biogas production at temperatures ranging from 8 to 13^{O}C. They reported an elevation of temperature from $8\text{-}10^{O}$C to $12\text{-}13^{O}$C (ambient winter temperature in southern China) would result in the doubling or quadrupling of biogas production. At temperatures of $12\text{-}13^{O}$C, they observed biogas production up 40% optimal (35^{O}C) production. Cullimore et al. (1985) reported a linear relationship with a high correlation between biogas production and temperature at a temperature range from 4^{O}C to 26^{O}C. Their conclusions were based on a two year study of a swine waste EMS at Craven, Saskatchewan.

Some researchers have found that with higher hydraulic retention times (HRT) lower temperature anaerobic digesters are able to produce biogas levels nearer to those having higher temperature and relatively shorter retention times (Steven & Schulte, 1979). It has also been found that low temperature digestion requires a longer solids retention time (SRT) to achieve the same VS reduction as mesophilic digestion (Safley & Westerman, 1992a). Additionally it has been found that equivalent rates of waste conversion to methane could be achieved at either higher temperatures or lower temperatures, if higher concentrations of bio-mass are held in the reactor at the lower temperatures. In essence, process performance could be independent of temperature with proportionate compensation for the reduced metabolic activity through increased microbial population (Dague & Pidapariti, 1992).

Procedure and Project Activities

The comparative study of manure quality between a covered and an open EMS was conducted on two farms in Manitoba, van Aert Farm, St. Clement, Manitoba, and the Preun Family Farm, St. Andrews, Manitoba.

The Preun Farm is a 350 sow farrow to finish operation. The barn temporarily stores manure in shallow pits (pull plug system), except in the grow-finish area, where the manure is removed daily with a mechanical scrapper. The Farm has a one cell EMS with a dimension of 250'X250' which was left open and used as a control EMS for the study.

The van Aert Farm is a 600 sow farrow to finish barn with shallow pits in all production area. This farm has a two cell EMS with primary cell dimensions of 140'X140' and secondary cell dimensions of 140'X390'. Both cells were covered with a 20 mil reinforced polyethylene plastic cover. The covers were anchored around the perimeter of each cell and maintained over the surface of each cell by use of a negative air pressure system equipped with a 1/3 HP centrifugal blower.

Filling of the primary cell of the covered EMS and open EMS began in October of 1999. Raw manure samples were collected monthly from the wet wells in barns from both sites beginning in February of 2000. During the same period, manure samples were collected from the open EMS and the first cell of the covered EMS. There were insufficient levels of manure in the secondary cell of the covered EMS at the outset of the study to provide meaningful samples. The secondary cell of the covered EMS first began to fill in January of 2000 and commencing late June of 2000 samples were collected from the second cell in addition to the first cell of the covered EMS. Sampling concluded at the end of August of 2000 on van Aert Farm and in early September of 2000 on the Preun Family Farm, respectively, which was concurrent with the emptying of each respective EMS for land application of the manure. In total, seven batches of samples were collected. Temperature at different layers of each EMS were measured and recorded monthly. Observations were made of biogas production in the covered EMS.

Raw manure samples were collected from the wet wells during pumping of the manure to the EMS. Sampling occurred at the commencement of pumping, the mid-point of pumping and near the completion of pumping to collect as representative a sample as possible.

Stored manure samples were collected with a 3/4" PVC pipe 20' in length. Twelve points were chosen along the berm of the open EMS for sampling. An opening was made at the edge of the covers at each cell of the covered EMS for sampling, whose openings were re-sealed with soil after samples were taken.

Samples were analyzed for pH, alkalinity, volatile solids (VS), Chemical Oxygen Demand (COD), Volatile Fatty Acids (VFA), Total Kjeldahl Nitrogen (TKN), dissolved Kjeldahl nitrogen, ammonia nitrogen, total phosphorus, and dissolved phosphorus. Samples were tested by Enviro-Test Laboratories, Winnipeg, Manitoba. The laboratory test methodologies are attached in appendix A.

Data for the covered EMS presented herein are based on the samples from the primary cell from February to May of 2000 and weighted mean values of the primary and secondary cells from June to August of 2000.

Results and Discussion

The results of laboratory tests on manure samples typically display a wide variation in the characteristics of the manure. Possible reasons for this variation include pig diet, pig age, manure handling and sampling methodology. To address this variation some researchers recommend expressing swine manure characteristics in terms of maximum, minimum, average and in some cases, standard deviation values (Campbell et al., 1997).

Nutrients Conservation

The primary nutrients in swine manure include nitrogen, phosphate and potash. There is virtually no loss of phosphorus or potassium in the process of EMS manure storage and treatment. Loss of nutrients from manure slurry in well-designed stores is generally confined to nitrogen lost to the atmosphere as ammonia or by denitrification as nitrogen.

The nitrogen excreted by hogs is in the form of protein and non-protein nitrogenous compounds. Most of the N in manure is in the form of non-protein nitrogenous compounds such as urea, uric acid, purine, hippuric acid, creatinine, creatine, and allantoin (Smith, 1973). Of those compounds urea nitrogen represents 70-90% of the urine nitrogen contents (Haynes and Williams, 1992). Urea is hydrolysed rapidly to ammonia and carbonaceous products. Ammonia nitrogen exists in slurry either in the form of free ammonia (NH_3) or in the form of ammonium (NH_4^+) depending on pH and temperature of slurry.

Table 4-1 shows systematic differences on nitrogen contents between the two EMS systems. With respect to the nitrogen concentrations of the influents to each EMS, mean values of the three nitrogen parameters (TKN, dissolved KN, and ammonia) in the influents to the open EMS were higher than those to the covered EMS. These differences in nitrogen concentration in the influents of each EMS may be caused by differing farm practices, including pig diet, manure handling, etc. With respect to the nitrogen concentrations of the stored manure, the results show the opposite: that mean values of the three nitrogen parameters in the covered EMS are higher than those in the open EMS.

Ammonia nitrogen, existing in forms of either ammonium ion (NH_4^+) or ammonia (NH_3), was the predominant form in the EMS influents, 59.3% in the open EMS influent and 72.6% in the covered EMS influent (Table 4-1). Such high ammonia nitrogen levels in the influents suggest that organic nitrogen hydrolysis occurred to a certain degree before the manure slurry entered the EMSs and probable ammonia loss had taken place, most notably in the barn with the covered EMS (72.6% ammonia nitrogen). This likely occurred because of the retention time in manure collecting pits. The pits were emptied at varying intervals of up to three weeks, depending on levels of manure production within the respective production area.

Table 4-1 Average Nitrogen Concentration in EMSs and Their Influents

Form of Nitrogen	Open EMS		Covered EMS	
	Influent	In EMS	Influent	In EMS
Total Kjeldahl Nitrogen (mg/L N)	4696	2930	3664	3423
Dissolved Kjeldahl Nitrogen (mg/L N)	3003	2640	2786	2969
Dissolved Ammonia (mg/L N)	2786	2134	2659	2706
Organic Nitrogen* (mg/L N)	1910	796	1005	717
Organic Nitrogen percentage	40.7%	27.2%	27.4%	20.9%
Ammonia percentage	59.3%	72.8%	72.6%	79.1%

*The organic nitrogen concentration is a calculated value that is the difference between the concentration of TKN and Dissolved ammonia.

The portion of ammonia nitrogen increased during storage by 13.5% (from 59.3% to 72.8%) in the open EMS and by 6.5% (from 72.6% to 79.1%) in the covered EMS, respectively. Concurrently, the organic nitrogen concentrations decreased by 1114 mg/L N in the open EMS and by 288 mg/L N in the covered EMS compared with their respective influents. The mineralization rate on organic nitrogen was 23.7% in the open EMS and 7.8% in the covered EMS. It is noteworthy that ammonia nitrogen was up to 72.6% of TKN in the influent in the covered EMS. This high ammonia ratio suggests that extensive hydrolysis had occurred before the manure entered the EMS. Since the more easily biodegradable organic nitrogen had been mineralised, the bacteria attack the hard decomposable part of organic nitrogen. As a result, a lower mineralization rate on the organic nitrogen was achieved in the covered EMS.

The TKN concentration in the open EMS reduced by 37.5% compared to that in its influent. This reduction is primarily the result of sedimentation of volatile solids (containing organic nitrogen) and volatilization of ammonia. The ammonia concentration dropped by 23.4% in the open EMS comparing to its influents. The quantity of nitrogen loss by means of volatilization is hard to measure. However, the value should be greater than 23.4% because a portion of organic nitrogen was converted to ammonia nitrogen during the period of storage.

The TKN concentration in the covered EMS was only 6.6% less than that of the influent to the covered EMS. It appeared that the reduction in TKN caused by settling was no more than 6.6% as there was ammonia loss in the biogas released to the atmosphere (4.2). The ammonia concentration increased slightly by 1.7% in the covered EMS. This represented the difference between the ammonia produced in organic matter decomposition and ammonia lost with biogas bubbles release.

Comparing the changes in TKN and ammonia nitrogen in the open EMS and the covered EMS systems, the results indicate that the covered EMS can reduce nitrogen loss by approximately 82% and maintain approximately 93% of the nitrogen levels in the influent during the storage period. The nitrogen conservation effect of the Negative Air Pressure Cover System is obvious.

Table 4-2 shows the changes in phosphorus concentration in the two EMS systems between influent and treated manure. In all four cases dissolved P accounts for approximately 70% or more of the total P. It should be considered highly available for plants.

Phosphorus concentrations significantly dropped in both the open and covered EMS systems during the storage period. Only 28.3% of the Total-P levels in the influent were found to remain in the treated manure in the open EMS, and only 42.3% of the Total-P levels in the influent were found to remain in the treated manure in the covered EMS. Similarly, only 26.5% of the dissolved P levels in the influent were found to remain in the treated manure in the open EMS, and only 58.4% of the dissolved P levels in the influent were found to remain in the treated manure in the closed EMS.

These reductions in phosphorus do not necessarily mean phosphorus is lost from the EMS. Theoretically, P should be 100% conserved during anaerobic digestion (Field et al., 1985) and any apparent losses are a result of phosphorus transfer from the liquids to the solids within the EMS. In a covered lagoon digester study, Safley and Westerman (1992a) found that the P concentrations in the effluent were 20 to 30% less than those in the influent. They explained this reduction as probable solids accumulating in the lagoon. The Hydraulic Retention Time used in their study was 67 days. In our study, the average manure storage period in the EMSs was more than 100 day. More P accumulation in the solids is not therefore unanticipated. Total-P in the settled solids accounts for more than 90% of the total in the EMS, even though the liquid occupies the greater portion of an EMS, (Bicudo et al., 1999). Field et al. (1985) pointed out that unstirred digestions of animal manures may have an important fraction of the manure P in the digester due to the settling of manure solids.

4-2 Summary of phosphorus in the open and the covered EMS

Parameters		Open EMS		Covered EMS	
		Influent (raw manure)	In EMS (stored manure)	Influent (raw manure)	In EMS (stored manure)
Total P (mg/L P)	Mean	1937	548	882	373
	Max	3070	1470	1320	661
	Min	532	200	448	204
	SD	870	425	312	179
Dissolved P (mg/L P)	Mean	1445	383	543	317
	Max	2460	503	855	564
	Min	404	197	153	177
	SD	754	113	229	142

The fates of nitrogen and phosphorus in manure slurry are different in an anaerobic EMS system. Nitrogen, primarily, is subjected to the conversion from organic to inorganic form. Nitrogen exists mainly in the liquid portion of an EMS. More than 60% NH_3-N and 70% of TKN are found contained in liquid portions of an EMS (Campbell et al. 1997). Phosphorus, on the other hand, moves by means of incorporating orthophosphate, polyphosphate, and organically bound phosphorus into bacteria cells and that settle down to the EMS bottom.

Biogas Production Potential

Biogas is a by-product of the anaerobic digestion of swine manure and normally consists of approximately 70% methane and 30% carbon dioxide. A commonly accepted value of methane productivity is 0.5 L/g VS destroyed (Metcalf and Eddy, 1991).

In this study, no biogas samples were collected. The discussion of the potential for biogas production will focus on the possibility of methane production by analysis of the volatile fatty acids (VFA) data collected in both EMS. The literature of recent years relating to anaerobic digestion of animal manure contains numerous observations suggesting volatile fatty acid relationships have direct correlation with digester performance and methane production. Acetic acid is known to be the immediate precursor of approximately 70% of all methane formed during digestion. Similarly, propionic acid is the immediate precursor to approximately 70% of acetic acid. These two acids play important roles in indication of successful methane production. Acetic acid concentrations lower than 800 mg/L and the ratio of propionic to acetic (P/A) lower than 1.4 are two indicators for successful methane production (Hill et al., 1987).

Table 4-3a and 4-3b illustrate the VFA in both the open and the covered EMS respectively. Acetic acid was the predominant form of VFA appearing in both EMS, suggesting that the carbonaceous organic matter in the swine manure had been decomposed or hydrolysed. The substrate is ready for methanogens to produce methane.

Table 4-3a VFA in the Open EMS

Types of VFA and carboxylic acid	Acid Concentration in the Open EMS						
	February	March	April	May	June	July	August
Formic acid	<100	<100	<100	<100	300	<100	<100
Acetic acid	12000	1600	3800	4800	3000	1300	230
Propionic acid	910	480	600	1400	1900	1100	<50
Butyric acid	380	300	260	420	70	40	<10
Isobutyric acid	120	70	50	190	170	30	<10
Valeric acid	90	70	40	140	70	20	<10
Isovaleric acid	120	80	30	170	310	30	<10
Caproic acid	30	50	20	50	<10	<10	<10

Table 4-3b VFA in the Covered EMS

Types of VFA and carboxylic acid	Acid Concentration in the Covered EMS						
	February	March	April	May	June	July	August
Formic acid	<100	<100	<100	<100	<100	<100	<100
Acetic acid	13000	3400	5400	4600	1900	120	270
Propionic acid	1200	1300	1500	1700	1500	<50	<50
Butyric acid	420	530	610	330	50	<10	<10
Isobutyric acid	200	270	330	290	250	<10	<10
Valeric acid	140	190	160	170	80	<10	<10
Isovaleric acid	160	250	260	220	210	<10	<10
Caproic acid	90	170	150	90	<10	<10	<10

Having methane production potential does not mean that methane will be successfully produced. In an analysis of the acetic acid concentration in the covered EMS (Table 4-3b), it can be seen that the acetic acid level remained high from February to June. High acetic acid levels usually mean methanogens have failed to convert acetic acid to methane and carbon dioxide. During above mentioned period, there was no significant methane production. The acetic acid concentration started to drop down between May and June. This reduction in acetic acid probably resulted from the formation of methane (Eq. 2-1). The following months' acetic acid data verified the hypothesis. By July and August, the acetic acid concentration levels were very low in the covered EMS, which is an indicator of successful methane production.

The observations of biogas production on the covered EMS support this conclusion. No bubbles of a significant size were observed under the cover from February to May. Large bubbles appeared in late May under the covers and very large bubbles were observed from June to August. No further observations were possible since the primary cell was emptied on August 31 and the secondary cell was emptied on September 1. The number, size and frequency of gas bubbles were not recorded in detail. The dimension of the bubbles formed in the secondary cell in a day is approximately 15 m in diameter and 2 m in height. The volume of bubbles is estimated as 35 to 60 m^3. The pressure in the bubbles is higher than barometric pressure because of the accumulation of precipitation on the surface of the cover. When the bubbles moved to the sides of the cell, the blower was able to discharge the gas into the atmosphere. It took the blower 10 to 20 minutes at flow-rates of 50 to 150 L/s to release the gases contained in the bubble. Based on the number and size of bubble as well as the frequency of bubble formation, the biogas production is estimated to be 100 to 300 m^3/day in the covered EMS (two cells) in the summer months. The number and size of bubble were usually larger in the secondary cell than that in the primary cell.

Acetic acid concentration levels in the open EMS also decreased over the course of the study (Table-4-3a, Figure 4-1). Figure 4-1 shows that the decrease in acetic acid started between June and July, which is one month later than that occurred in the covered EMS. Similarly, acetic acid concentration dropped to below 800 mg/L in August, which also happened one month later than that did in the covered EMS. These facts indicate that biogas production occurred later in the open EMS than in the covered EMS.

The most probable reason for later methane production in the open EMS than in the covered EMS is that the temperatures in the open EMS were lower than those in the covered EMS. A comparison of the average temperatures in the open and covered EMS between May and August shows the covered EMS was approximately 4-5^{o}C warmer than the open EMS during that period (Figure 4-1). Temperature differences at the bottom of the two EMS were even bigger (Figure 4-3). The temperatures at the bottom of an EMS are significant since most of the biomass, including methanogens, are situated at the bottom.

An analysis of propionic concentrations in both EMS shows that the ratio of propionic acid to acetic acid (P/A) remained low in both the EMSs. The maximum P/A in the covered EMS was 0.79, which occurred in June. The maximum P/A in the open EMS was 0.85, which occurred in July. P/A ratios lower than 1.4 indicates that proton-reducing acetogens are more active or, at lest, not less active than acetate-utilizing methanogens in the EMS (Eq. 4-1, 2-1, and 2-2). It appears that reduced methanogens activity is the cause of failure in biogas production in spring and winter.

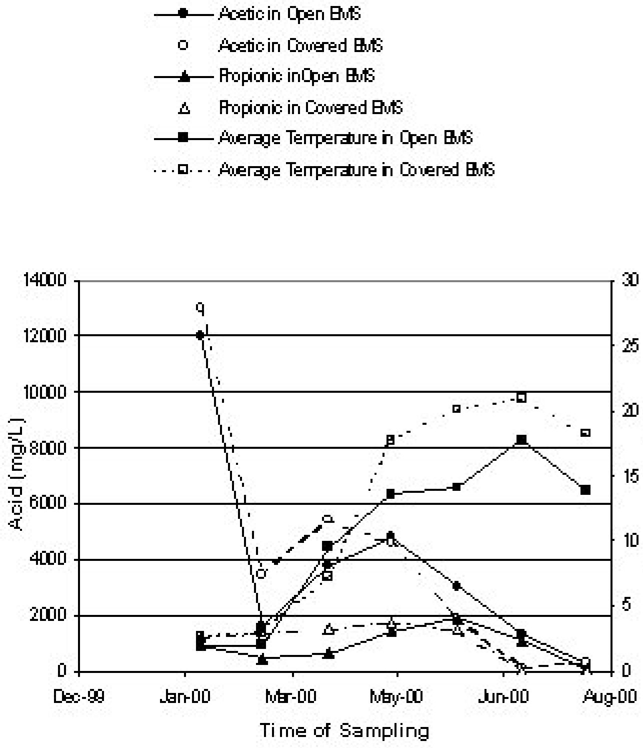

Figure 4-1 Acetic or Propionic Acid Concentration and Temperature in the EMSs with or without a Cover

$$CH_3CH_2COOH + 2H_2O \xrightarrow{\text{proton-reducing acetogens}} CH_3COOH + CO_2 + 3H_2 \quad (4\text{-}1)$$

$$CH_3COOH \xrightarrow{\text{acetate-utilizing methanogens}} CH_4 + CO_2 \quad (2\text{-}1)$$

acetate-utilizing methanogens
$4CH_3COOH$ ¾ ¾ ¾ ¾ ¾ ¾ ¾ ¾ ¾ ¾ ¾ ® $3CH_4 + CO_2 + H_2O$ (2-2)

There are several factors which impact the activity of methanogenic bacteria. Excess acid, oxygen, or toxic substances, extremes in pH or temperature may all act to inhibit methanogenic completion (Henry & Heinke, 1989). In this study, temperature seems to be the key factor. It is worthwhile to note that the decrease in acetic acid correlates to the increase in temperature in both the covered and the open EMS. The temperature and acetic acid data obtained in this study were consistent with reports that methanogenesis occurs at 4^{o}C and that productivity increases with increases in temperature (Steven & Schulte, 1979, and Safley & Westerman, 1992a).

There was a sharp decrease in the acetic acid concentration from February to March in both the covered EMS and the open EMS. The reason causing this kind of decrease is unclear.

Alkalinity, pH and Temperature

The pH levels in both the covered EMS and the open EMS were fairly constant within a similar range of 7.60± 0.19 and 7.57± 0.21, respectively (Table 4-4). Maintaining pH levels in this range is very important to the successful production of methane (complete decomposition of the organic matters). Methanogens do not work well at low pH and if pH is lower than 6.2, the methanogens cannot function (Metcalf & Eddy, 1991). High pH may also impact methanogens' activity since ammonium (NH_4^+) converts to free ammonia (NH_3) at high pH, the latter being much more toxic to bacteria. The main concern with pH in anaerobic digestion is a decrease in pH because larger quantities of organic acids are produced during organic matter decomposition.

Table 4-4 pH in the EMSs and their influents

Samples	pH value in the Samples										
	Feb.	Mar.	April	May	June	July	Aug.	mean	max	min	SD
Influent to open EMS	7.48	6.93	7.50	6.81	6.57	6.43	6.10	6.83	7.50	6.10	0.54
In open EMS	7.69	7.82	7.45	7.27	7.51	7.77	7.46	7.57	7.82	7.27	0.21
Influent to covered EMS	7.18	7.34	7.72	7.23	7.33	7.38	7.49	7.38	7.72	7.18	0.20
In covered EMS	7.55	7.65	7.52	7.35	7.59	7.90	7.66	7.60	7.90	7.35	0.19

The alkalinity in both the covered EMS and the open EMS are almost totally bicarbonate alkalinity (BA). The carbonate and hydroxide alkalinity kept below 20 mg/L and 10 mg/L, respectively, in both the open and covered EMS during the entire study period. The ratio of bicarbonate alkalinity (BA) to total alkalinity (TA) is a good indication of the occurrence of digestion. The BA/TA values for the EMS liquid are above 0.85 indicating good biological 'health' (Pos et al., 1985). In fact the BA/TA value for the EMS liquid indicates that the EMS may be underfed biologically (Safley & Westerman, 1989).

Figure 4-2 illustrates that pH levels were fairly constant in both the open and covered EMS during the entire study period. The VFA produced in the acidogenesis phase during anaerobic digestion is neutralised by the alkalinity in the manure.

The temperatures in both open and covered EMS were recorded during the period that manure sampling occurred. EMS temperatures were measured at different depths. At the commencement of sampling of this study in late February, the surface of both the covered and open EMS was frozen and the surfaces of both EMS melted in mid-March.

Figure 4-3 indicates that EMS temperatures varied widely throughout the entire study period. The covered EMS temperature is consistently higher than the open EMS temperature over the entire study period with the exception of April, when the reverse is true. The temperature variation over time shows that the temperatures, from February to April, were low (below 10 ^{o}C). These low temperatures are not conducive to anaerobic digestion (biogas production). During that period, no significant biogas can be expected. From May to August, the temperatures in the open and the covered EMS stood above 12^{o}C. Methane production of 0.2 L/g VS destroyed may be expected in the both EMSs in May according to Safley & Westerman (1992a). In this study, however, no significant biogas production occurred in May. Other factors in addition to low temperature are therefore responsible for gas production.

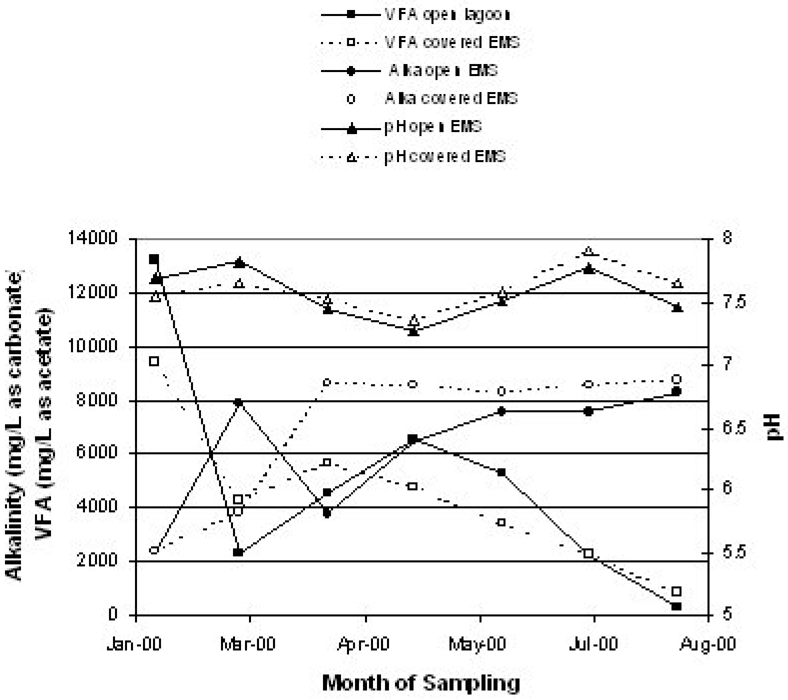

Figure 4-2 VFA, Alkalinity and pH in The Lagoon with and without a Cover

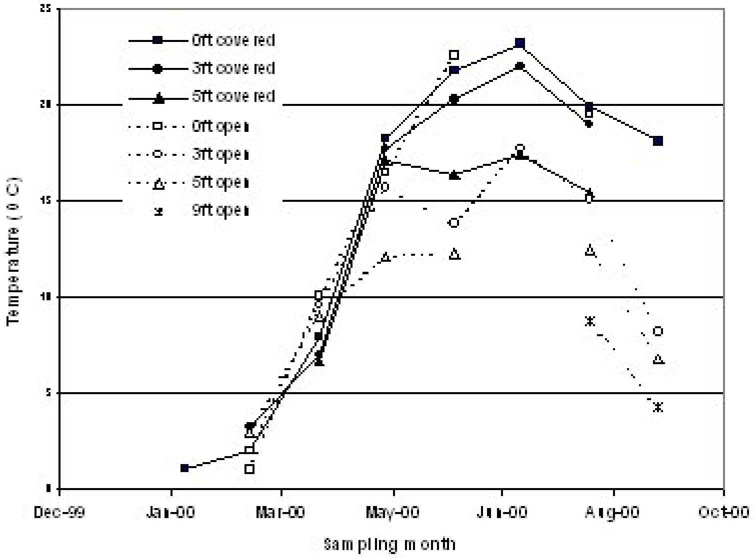

Figure 4-3 Temperature variation in EMSs with depth and with time

1. Temperature at a certain depth in the covered EMS is higher than tha in the open EMS.
2. Temperatures started to rise from March and reach the top value in July, in both EMS.
3. It seems that the average temperatures in the EMS are above 10ºC from May to September, which minimum temperature for biogas production.

From February to May little difference in temperature occurred between the covered EMS and the open EMS. From May to August, the average temperature in the covered EMS is 4 to 5^{O}C higher than those in the open EMS.

The EMS temperature is a function of depth. Surface temperatures are lower than temperatures taken at depth in the winter, and surface temperatures are higher than temperatures taken at depth in the summer. The variation in temperatures with depth is greater in the open EMS than in the covered EMS (Figure 4-3). The temperature differences during summer months between the surface and at the depth of 5 ft were approximately 5^{O}C in the covered EMS and 10^{O}C in the open EMS. This would suggest that deep (deeper than 7 feet) uncovered EMS are not suitable for use as an anaerobic digester because the temperatures at the bottom (around 10^{O}C) are below temperatures at which anaerobic digestion can occur efficiently.

Organic matter decomposition

Table 4-5a and Table 4-5b illustrate the properties of the organic matter in the EMS influents in the EMSs. Relatively large standard deviations (SD) are found for all organic parameters.

Table 4-5a Organic matter in the open EMS influent and in the open EMS

Parameters	Influent (raw manure)					In EMS (stored manure)					removal
	Mean	Max	Min	SD		Mean	Max	Min	SD		Mean
TCOD (mg/L)	55000	110000	21000	30425		14786	23000	5900	6458		73.1%
Soluble COD (mg/L)	16271	24000	5900	6103		7714	14000	3000	3622		52.6%
VS (mg/L)	32000	88000	7000	28601		5129	8400	2300	2486		84.0%
VFA (mg/L as acetate)	7111	9912	5708	1445		4947	13218	360	4208		30.4%

Table 4-5b Organic matter in the covered EMS influent and in the covered EMS

Parameters	Influent (raw manure)					In EMS (stored manure)					removal
	Mean	Max	Min	SD		Mean	Max	Min	SD		Mean
TCOD (mg/L)	38143	57000	16000	13813		19790	32000	6500	8660		48.1%
Soluble COD (mg/L)	8800	17000	2700	4943		9078	14000	2940	4471		-3.2%
VS (mg/L)	27543	67000	4800	21675		6836	13000	1840	3647		75.2%
VFA (mg/L as acetate)	4836	7438	1374	2203		4416	9439	896	2736		8.7%

Total Chemical Oxygen Demand (TCOD) is used as the measurement of organic concentration in swine slurry and is related to biogas production and cell synthesis. Soluble COD (SCOD) represents the soluble parts of TCOD. The difference between TCOD and SCOD is insoluble or solid COD. Since micro-organisms can only use dissolved and some colloidal organic matter, insoluble COD is seldom discussed in research papers. Insoluble COD can be converted into soluble COD by hydrolytic enzymes. As a result of hydrolysis, SCOD increases, solid COD decreases, TCOD, however, does not change. In a stepwise process, acidogenesis and methanogenesis bacteria decompose the hydrolysis products to inorganic matter, mainly methane and carbon dioxide (known as gas COD, Yang & Moengangongo 1987), or synthesize the hydrolysis products to a cell component that is a kind of insoluble COD.

Volatile Solids (VS) are another measure of organic matter and contribute to TCOD. VS can be classified as Volatile Suspended Solids (VSS) and Volatile Filtrable Solids (VFS). Most of VSS can be removed by sedimentation. As VSS are settled, a portion of solid COD is removed from the liquid.

Volatile Fatty Acids are a component of SCOD, and their removal is mainly by means of methanogenesis biological removal) or volatilization (physical removal).

From the above discussion, it is found that organic matter removal is the comprehensive effect of physical (sedimentation & volatilization) and biological (methanogenesis) processes taking place in an anaerobic digester. Yang & Moengangongo (1987) reported that in a controlled anaerobic digestion, physical removal efficiency (57%) played a dominant part in the overall removal mechanism as compared to the biological removal efficiency (20%). The physical and biological removal efficiencies in lagoons or EMSs is not available in the literature.

Comparing the concentrations of TCOD, SCOD, VS and VFA in the open EMS to its influent concentrations gives an indication of the degree of treatment accomplished by the EMS. The reductions in TCOD, SCOD, VS, and VFA in the open EMS were 73%, 53%, 84% and 30% respectively. The corresponding reductions in the covered EMS were 48%, -3%,75% and 9%, respectively.

There was a large difference in TCOD removal between the two EMSs that mainly resulted from the difference in SCOD removal (reduced by 53% in the open EMS; increased by 3% in covered EMS). As mentioned above, SCOD removal can be accomplished by either biological degradation that is closely related to methane yield, or by volatilization of VFA. From the Table 4-3, it is evident that methanogenesis probably took place in one month (August) in the open EMS. Biological removal was therefore very limited. The probable explanation is that the 53% reduction in SCOD resulted primarily from the volatilization of VFA (that reduced by 30% during the same period). In the covered EMS, VFA volatilization was almost eliminated (minimal release to the atmosphere happened while biogas bubbles were discharged). Consequently, limited physical removal of VFA occurred. The 9% VFA removal resulted mainly from methanogenesis. It can therefore be concluded that the open EMS volatilizes VFA and that this is probably a primary source of odour from open EMS.

The previous discussion was a simplified analysis. The actual change in organic matter during storage is more complicated because some settled organic solids could be hydrolyzed to oligomers or monomers and be metabolized to volatile acids added to dissolved organic matter. If this dissolved organic matter is not physically removed (volatilization) or biologically removed (methanogenesis), it will accumulate in an EMS and result in low removal of TCOD and VS, and an increase in SCOD and VFA. This is what appears to have happened during the first five months (February to June) of this study in the covered EMS. The VFA biological removal (9%) in the covered EMS took place during summer (July to August).

No significant stabilisation (methanogenesis) of organic matter took place in the winter in either the covered EMS or the open EMS. Biogas production (an indication of stabilisation) was observed in the covered EMS from late May to the end of this study in late August. The notable stabilisation of organic matter (VFA decrease) started a month later in the open EMS in June and lasted to the end of the study in early September.

The low stabilisation rate of organic matter in the winter and spring, that occurred in both the covered EMS and the open EMS, was as a result of:

1. Cold temperatures ¾ The temperatures in both the open and covered EMS were below the minimum digester temperature of 10^{o}C (Safley & Westerman, 1992a).
2. Low methanogens population ¾ The covered lagoon digester can achieved 40% of optimum biogas production at a temperature of 13^{o}C (Safley & Westerman, 1992a). In this study, however, there was no significant biogas production in the covered EMS at 17^{o}C. It is noteworthy that lagoon digesters used in the USA always keep sludge (anaerobic bio-mass) at the bottom. There were few anaerobic microbes available at the beginning of the storage in the EMSs, however, because the EMSs were agitated and emptied.

Conclusions

The quality of manure was similar regardless of whether it was stored in the open EMS or in the covered EMS: organic matter was partially decomposed; nitrogen existed mainly in liquid portion; and phosphorus exists mainly in sediments. However, a covered EMS has some advantages over an open EMS.

The covered EMS can retain significantly more nutrient by preventing ammonia from releasing into the atmosphere. The nitrogen loss from the open EMS is approximately 37.5%. Nitrogen loss from the covered EMS is 6.6%. The EMS covered with a Negative Air Pressure Cover System is able to reduce nitrogen loss by 82% compared to the open EMS.

Nitrogen in the EMS is primarily in the form of NH_3-N that is ready for the rapid conversion to NO_3–N after manure application. This is of benefit to the initial crop intake following application. The portion of TKN that is NH_3-N is 79.1% in the covered EMS and 73.4% in the open EMS respectively.

Significant biogas production accompanied by a reduction in acetate acid was observed after June in the covered EMS. The biogas production is estimated to be 100 – 300 m^3/day. Based on the acetic acid analysis, biogas production probably started in July in the open EMS, a month later than in the covered EMS. No significant biogas production was observed during winter and spring in the covered EMS.

A higher organic matter removal (73% TCOD) was obtained in the open EMS than in the covered EMS (48% TCOD). The higher removal in the open EMS seemed to be related to VFA emission (physical removal). The volatilization of these VFA's from the open EMS is a major contribution to odour.

The effectiveness of the negative pressure system in retaining heat was observed. The average temperature was 5^{o}C higher in the covered EMS than that in the open EMS during the period from June to September. The higher temperature in the covered EMS resulted in one month earlier biogas production in it than in the open EMS.

The temperatures in the EMSs varies with depth. If an EMS is deeper than 7 feet, the temperature at its bottom will hardly reach 10^{o}C, which hinders the activity of methanogens.

Low initial biomass in the EMSs is a contributing reason for the low stabilization rate achieved in the early storage period. To increase biomass population, some sediments should be kept in EMS at the time the EMS is emptied.

Suggestions for Future Study

This study has demonstrated that significant potential to harvest biogas may exist in a covered storage. Some adaptations of the storage management might yield significant useful energy. For example, in the study a biogas yield of 200 m^3/day over the period of April 15 to August 30 would produce 650 gigajoules of energy, with a value of $3500 at current natural gas prices.

Specific activities which may enhance the knowledge and understanding of potential opportunities includes the following:

- A bench study on VFA removal by volatilization and by methanogenesis
  Investigating VFA change during manure stored in an open storage and covered storage. The study would be conducted with inoculation and without inoculation. In this study, the relationship between organic parameters

(TCOD, SCOD, TS, TSS, VS, VSS, VFA) could be established that can improve the understanding on the fate of organic matter during storage. The study will further the understanding of the mechanism of the NAP cover on odour control.

- An inoculation study in a covered EMS
  This study would show the effect of bacteria population on the organic matter stabilization and biogas production by leaving the sediments in the EMS following manure application. Biogas production and temperature in EMS would be observed. The hypothesis of this study is that biogas production starts at 13 to 15°C (approximately in April) and lasts for six months (from April to October). The composition of the biogas produced should be analyzed.
- A study on heated and agitated covered EMS
  Providing limited heat to the EMS to keep the temperature at around 15°C during winter and spring. Recovering biogas for EMS heating. Analyzing the effect of organic matter stabilization and odour elimination.

Acknowledgements

In December of 1999, DGH Engineering Ltd. received a research grant from Manitoba Livestock Manure Management Initiative to evaluate changes in the composition of manure during its storage in covered earthen manure storage basins. The primary purposes of the study were twofold: to determine the impact of covers on the conservation of nutrients in stored manure; and to evaluate the role of covers in the stabilisation of organic matter in manure. This study was conducted at two locations, the van Aert Family Farm near St. Clement, Manitoba and the Preun Family Farm near St. Andrews, Manitoba.

From the study, it has been found that nitrogen losses can be reduced by as much as 82% through the use of a cover, and that although the extent of stabilisation of organic matter in manure is comparable for both covered and uncovered earthen manure storages during the winter and spring, covered earthen manure storages experience stabilisation of organic matter, as evidenced by reductions in VFA concentrations, at an earlier point in time in the summer than uncovered earthen manure storages.

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